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April 1940

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INFORMATION CIRCULAR

UTILIZATION OF NATURAL GAS FOR CHEMICAL PRODUCTS

BY

HAROLD M. SMITH

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INFORMATION CIRCULAR

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

UTILIZATION OF NATURAL GAS FOR CHEMICAL PRODUCTS[1]

By Harold M. Smith[2]

Natural gas has been used as a fuel and source of energy almost from its discovery, but its use as a chemical raw material may be said to have begun in 1918, when Brooks and Humphrey[3] showed the presence of alcohols in the diluted acid oil obtained by the sulfuric acid treatment of cracked petroleum distillates. However, development of the utilization of natural gas for chemical syntheses was slow, partly because erroneous ideas existed regarding the nonreactivity of the hydrocarbons composing natural gas. Data accumulated by petroleum chemists throughout the world, particularly since about 1930, have shown that these hydrocarbons will react when activated by the effects of heat, pressure, chemical reagents, and light; also that the reactions can be made to proceed at practicable speeds and to provide good yields of useful products with moderate operating conditions, especially if catalysts are employed. As these results became known, the possibility of a synthetic organic chemical industry based upon these reactions became apparent, and today this industry is large and growing rapidly in importance.

In this paper the story of the manufacture of chemical products from natural gas is told simply in graphic form. The industry is developing so rapidly that some products may have been omitted, but every effort has been made to include all that are important or likely to become so. The difficulty of keeping information of this type up to date is shown by reference to an information circular[4] on the same subject published by the Bureau of Mines in 1930, in which the important products are shown on a single chart, whereas five charts are employed for the same purpose at present.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7108."

[2] Petroleum chemist, Bureau of Mines, Bartlesville, Okla.

[3] Brooks, B. T., and Humphrey, I., The Action of Concentrated Sulfuric Acid on Olefins, With Particular Reference to the Refining of Petroleum Distillates: Jour. Am. Chem. Soc., vol. 40, 1918, pp. 822-856.

[4] Smith, H. M., Possible Utilization of Natural Gas for the Production of Chemical Products: Bureau of Mines Inf. Circ. 6388, 1930, 5 pp.

It would be desirable to include brief descriptions of some of the processes, but operating conditions are so varied that no simple method of explanation seems possible. The subject of catalysts also is so complex that it cannot be covered adequately in a report of this type. The nontechnical reader is interested mainly in the general picture shown by the 10 charts; the technical reader will be able to obtain from the references given such chemical and engineering information as is generally available.

Chart I.

Chart I shows the general composition and major uses of natural gas. The percentage of the various components in natural gas varies greatly, but "wet" gas typical of much of that produced lies within the following limits in percent by volume: Methane, 80-90 percent; ethane, 5-10 percent; propane, 3-5 percent; isobutane and butane, 1-2 percent; pentanes and hexanes, 1-2 percent. Chart I also indicates that portion of natural gas, namely, "dry" and "liquefied" gas, with which this paper deals.

Chart II.

The upper graph of chart II shows the consumption of natural gas in 1938 for domestic, commercial, and industrial purposes. Unfortunately, figures for the quantity of natural gas used in the manufacture of synthetic chemicals have not been segregated, but are included under "other industrial" uses. The graph at the lower left shows the great increase in production of non-coal-tar synthetic organic chemicals from 1925 to 1938. However, statistics showing the proportion of increase due to synthesis from natural gas are not available. The graph on the right shows the consumption of liquefied propane and butane; statistics of the amounts used in chemical manufacture indicate a considerable increase from 1936 to 1938. The 31 million gallons used in 1938 would represent about 1 billion cubic feet in the gaseous state.

Chart III.

At present there are four basic methods of converting natural-gas hydrocarbons to other products. These are named, defined, and illustrated by examples in chart III. "Dehydrogenation" is considered as one type of "decomposition" and included under that heading. A few words concerning methane may be needed. Although it is the major constituent of natura gas, it was not chosen to illustrate the reactions because in most instanc it requires severe operating conditions, and the reactions are difficult to control. Methane can be decomposed by heat to give unsaturated gases and aromatic liquids, but extreme temperatures are necessary, and the processes are not economically feasible at present. Oxidation of methane is being carried out at present, and chlorination of methane is possible, but it is difficult to control the conditions so as to give a good yield of a single product rather than a mixture of three or four products.

Original from THE OHIO STATE UNIVERSITY

NATURAL GAS

NATURAL GAS IS A MIXTURE OF HYDROCARBON AND NON-HYDROCARBON GASES.

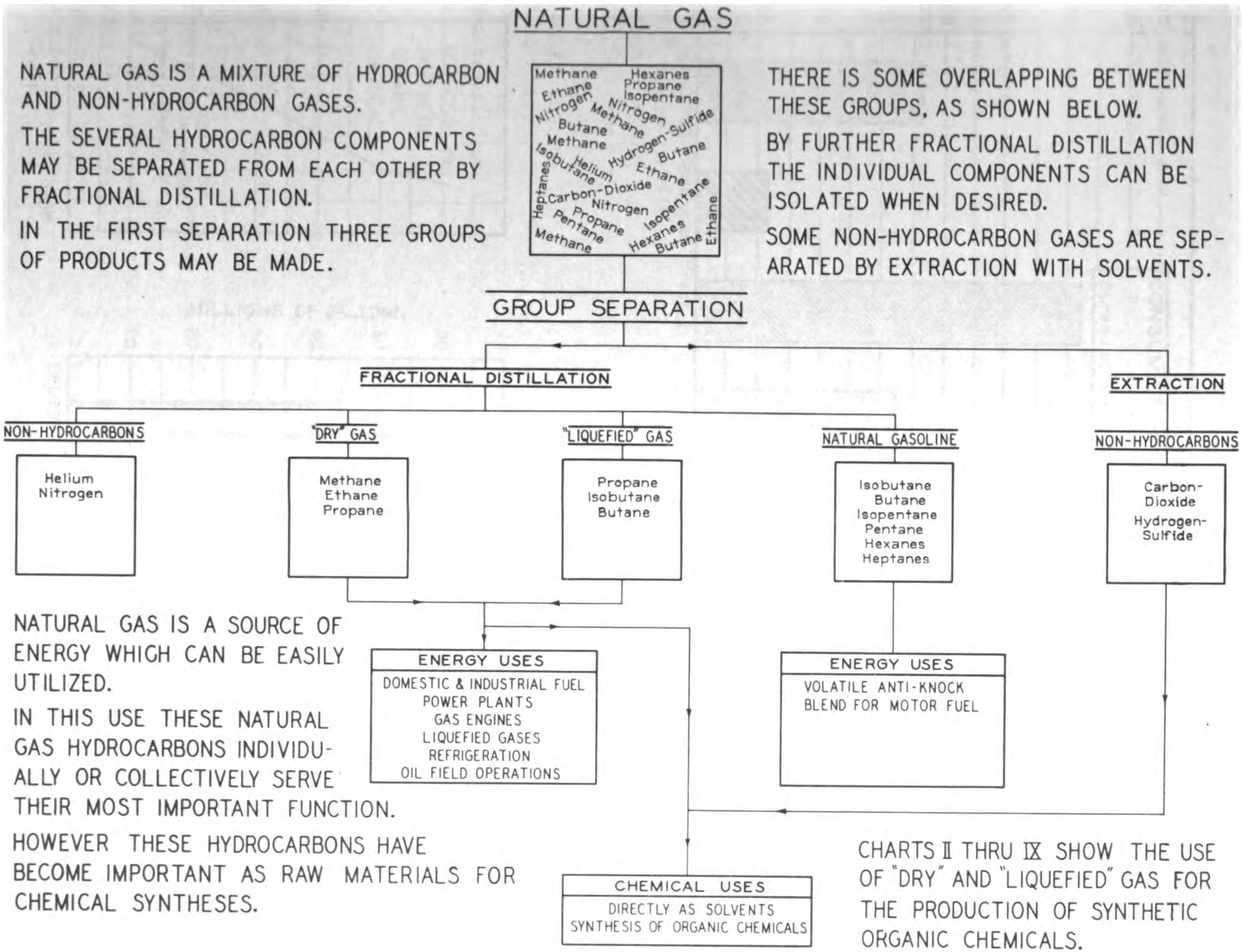
THE SEVERAL HYDROCARBON COMPONENTS MAY BE SEPARATED FROM EACH OTHER BY FRACTIONAL DISTILLATION.

IN THE FIRST SEPARATION THREE GROUPS OF PRODUCTS MAY BE MADE.

THERE IS SOME OVERLAPPING BETWEEN THESE GROUPS, AS SHOWN BELOW.

BY FURTHER FRACTIONAL DISTILLATION THE INDIVIDUAL COMPONENTS CAN BE ISOLATED WHEN DESIRED.

SOME NON-HYDROCARBON GASES ARE SEPARATED BY EXTRACTION WITH SOLVENTS.



NATURAL GAS IS A SOURCE OF ENERGY WHICH CAN BE EASILY UTILIZED.

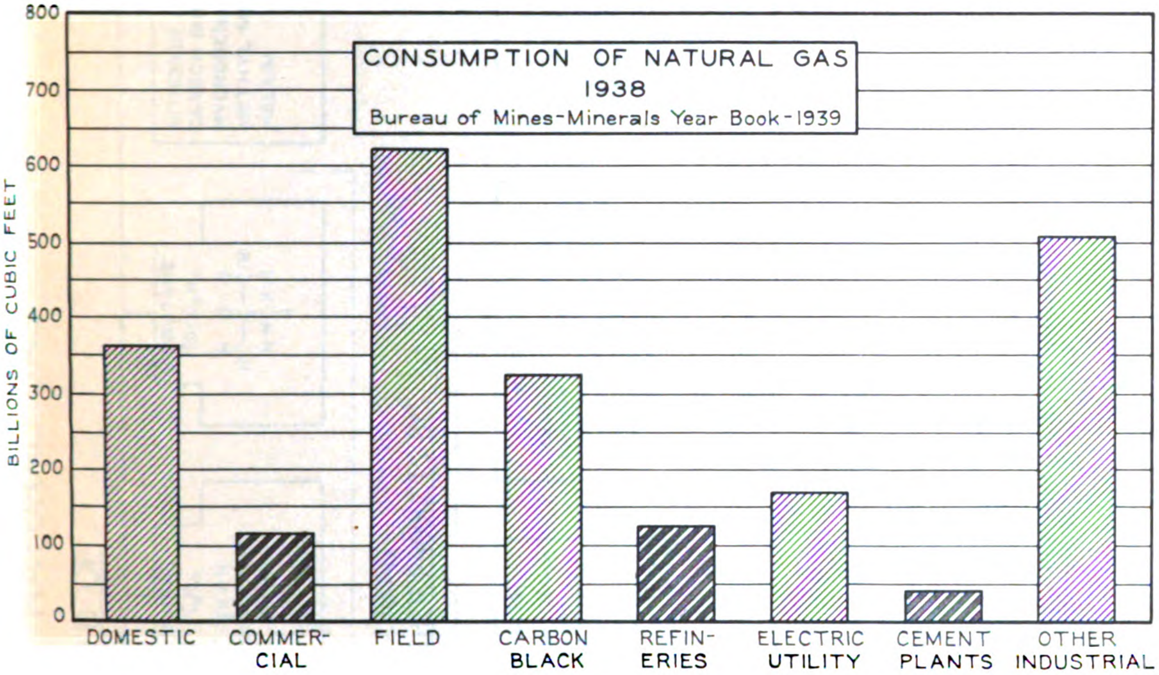
IN THIS USE THESE NATURAL GAS HYDROCARBONS INDIVIDUALLY OR COLLECTIVELY SERVE THEIR MOST IMPORTANT FUNCTION.

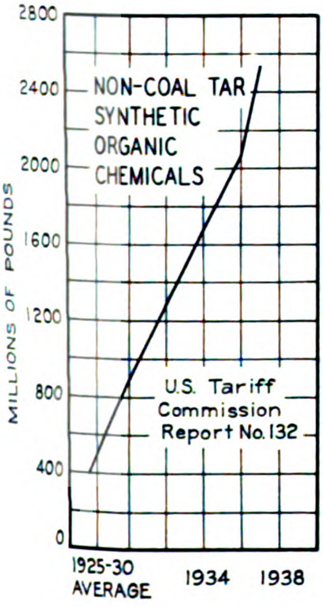
HOWEVER THESE HYDROCARBONS HAVE BECOME IMPORTANT AS RAW MATERIALS FOR CHEMICAL SYNTHESES.

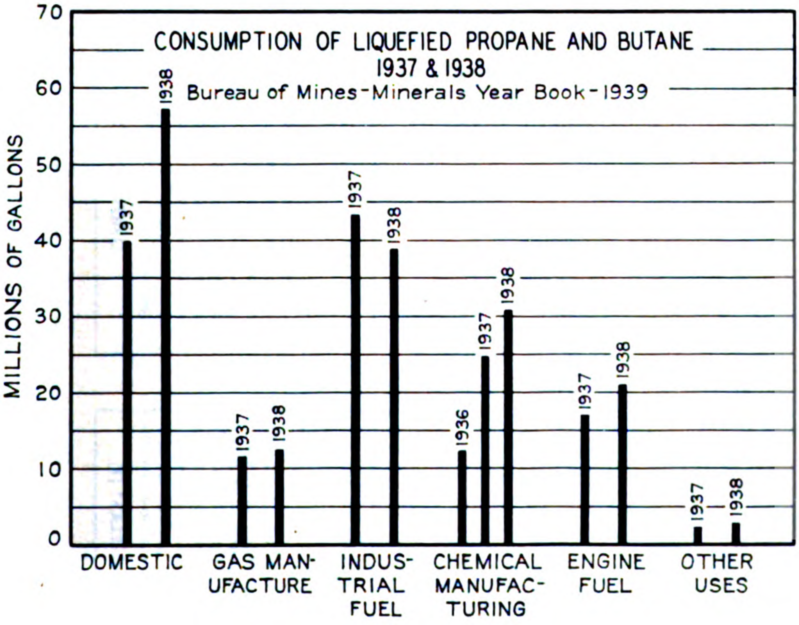
CHARTS II THRU IX SHOW THE USE OF "DRY" AND "LIQUEFIED" GAS FOR THE PRODUCTION OF SYNTHETIC ORGANIC CHEMICALS.

Original from THE OHIO STATE UNIVERSITY

CHART II

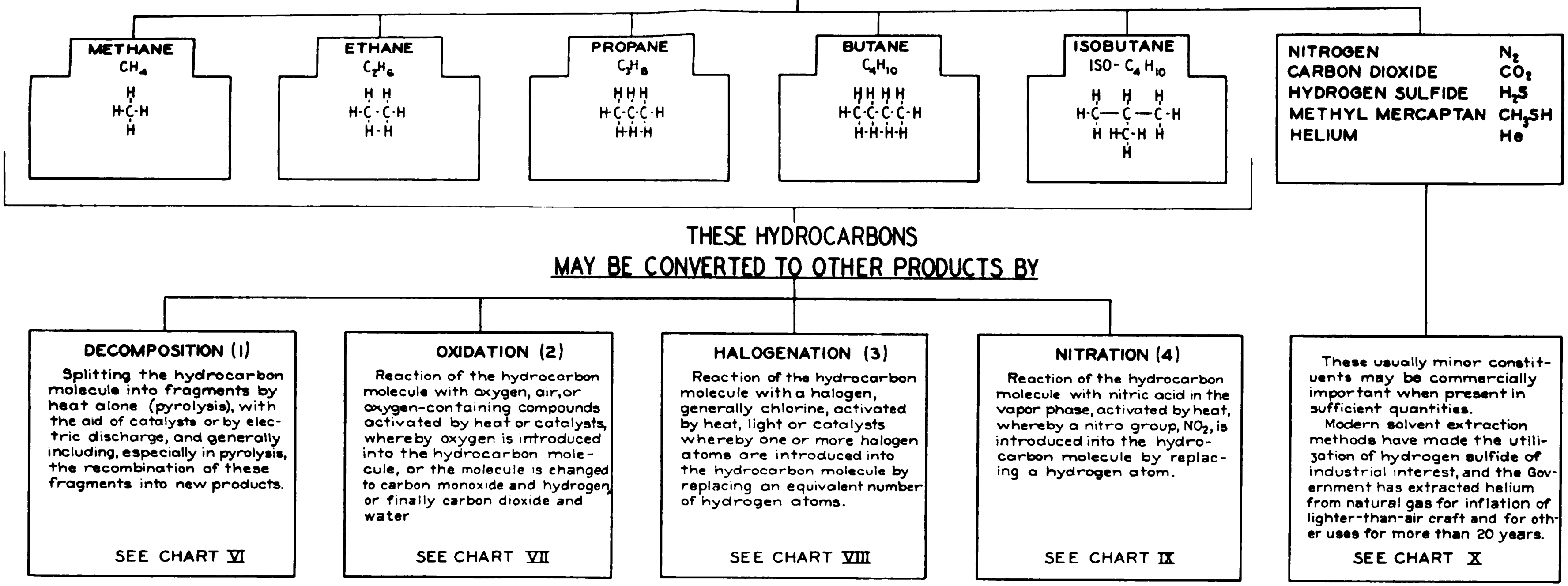

CONSUMPTION OF NATURAL GAS
1938
Bureau of Mines-Minerals Year Book-1939
BILLIONS OF CUBIC FEET
800
700
600
500
400
300
200
100
0
DOMESTIC
COMMER-CIAL
FIELD
CARBON BLACK
REFIN-ERIES
ELECTRIC UTILITY
CEMENT PLANTS
OTHER INDUSTRIAL


NON-COAL TAR SYNTHETIC ORGANIC CHEMICALS
U.S. Tariff Commission Report No. 132
MILLIONS OF POUNDS
2800
2400
2000
1600
1200
800
400
0
1925-30 AVERAGE
1934
1938


CONSUMPTION OF LIQUEFIED PROPANE AND BUTANE
1937 & 1938
Bureau of Mines-Minerals Year Book-1939
MILLIONS OF GALLONS
70
60
50
40
30
20
10
0
1937
1938
1937
1938
1937
1938
1936
1937
1938
1937
1938
1937
1938
DOMESTIC
GAS MAN-UFACTURE
INDUS-TRIAL FUEL
CHEMICAL MANUFAC-TURING
ENGINE FUEL
OTHER USES

"DRY" AND "LIQUEFIED" NATURAL GAS

IS COMPOSED OF



METHANE
CH_4

ETHANE
C_2H_6

PROPANE
C_3H_8

BUTANE
C_4H_{10}

ISOBUTANE
ISO- C_4H_{10}

NITROGEN	N_2
CARBON DIOXIDE	CO_2
HYDROGEN SULFIDE	H_2S
METHYL MERCAPTAN	CH_3SH
HELIUM	He

THESE HYDROCARBONS
MAY BE CONVERTED TO OTHER PRODUCTS BY

DECOMPOSITION (1)

Splitting the hydrocarbon molecule into fragments by heat alone (pyrolysis), with the aid of catalysts or by electric discharge, and generally including, especially in pyrolysis, the recombination of these fragments into new products.

SEE CHART VI

OXIDATION (2)

Reaction of the hydrocarbon molecule with oxygen, air, or oxygen-containing compounds activated by heat or catalysts, whereby oxygen is introduced into the hydrocarbon molecule, or the molecule is changed to carbon monoxide and hydrogen or finally carbon dioxide and water

SEE CHART VII

HALOGENATION (3)

Reaction of the hydrocarbon molecule with a halogen, generally chlorine, activated by heat, light or catalysts whereby one or more halogen atoms are introduced into the hydrocarbon molecule by replacing an equivalent number of hydrogen atoms.

SEE CHART VIII

NITRATION (4)

Reaction of the hydrocarbon molecule with nitric acid in the vapor phase, activated by heat, whereby a nitro group, NO_2, is introduced into the hydrocarbon molecule by replacing a hydrogen atom.

SEE CHART IX

These usually minor constituents may be commercially important when present in sufficient quantities.

Modern solvent extraction methods have made the utilization of hydrogen sulfide of industrial interest, and the Government has extracted helium from natural gas for inflation of lighter-than-air craft and for other uses for more than 20 years.

SEE CHART X

EXAMPLES OF THESE REACTIONS WITH ETHANE ARE

(1) Ethane C_2H_6 $\xrightarrow{\text{Heat, Catalysts}}$ Hydrogen H_2 + Ethylene C_2H_4

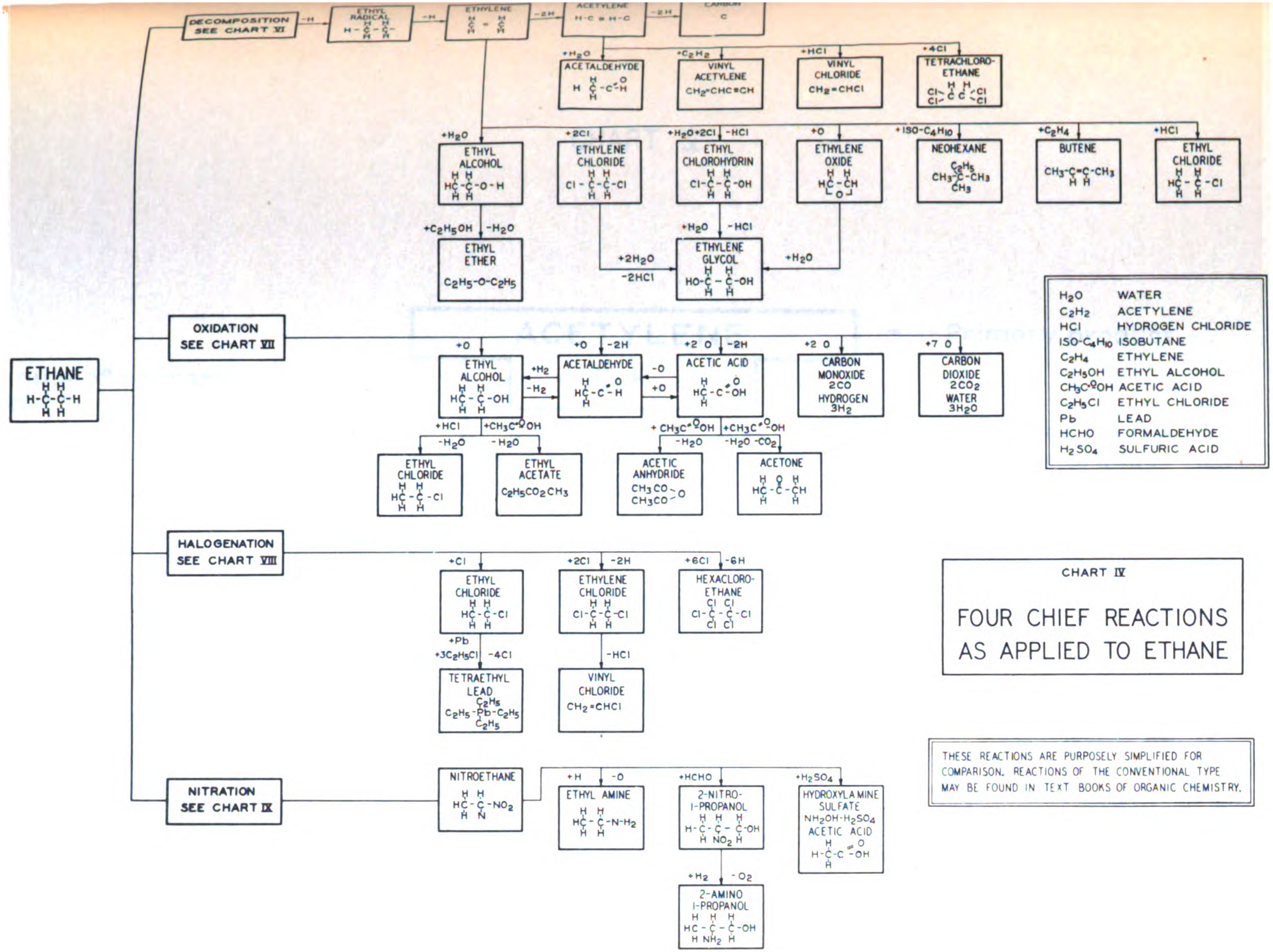
(2) Ethane $2\,C_2H_6$ + Oxygen O_2 $\xrightarrow[\text{Catalysts}]{\text{Heat, Pressure}}$ Ethyl alcohol $2\,C_2H_5OH$

(2) Ethane C_2H_6 + Steam $2\,H_2O$ $\xrightarrow{\text{Heat, Catalysts}}$ Hydrogen $5\,H_2$ + Carbon monoxide $2\,CO$

(3) Ethane C_2H_6 + Chlorine Cl_2 $\xrightarrow[\text{Catalysts}]{\text{Heat, Light}}$ Ethyl chloride C_2H_5Cl + Hydrogen chloride HCl

(4) Ethane C_2H_6 + Nitric acid HNO_3 $\xrightarrow{\text{Heat}}$ Nitroethane $C_2H_5NO_2$ + Water H_2O

Original from THE OHIO STATE UNIVERSITY


ETHANE H-C-C-H
DECOMPOSITION SEE CHART VI
-H
ETHYL RADICAL H-C-C-
-H
ETHYLENE
-2H
ACETYLENE H-C≡H-C
-2H
CARBON C
$+H_2O$ ACETALDEHYDE
$+C_2H_2$ VINYL ACETYLENE CH_2=CHC≡CH
+HCl VINYL CHLORIDE CH_2=CHCl
+4Cl TETRACHLORO-ETHANE
$+H_2O$ ETHYL ALCOHOL HC-C-O-H
+2Cl ETHYLENE CHLORIDE Cl-C-C-Cl
$+H_2O$+2Cl -HCl ETHYL CHLOROHYDRIN Cl-C-C-OH
+O ETHYLENE OXIDE
$+ISO-C_4H_{10}$ NEOHEXANE
$+C_2H_4$ BUTENE CH_3-C=C-CH_3
+HCl ETHYL CHLORIDE HC-C-Cl
$+C_2H_5OH$ $-H_2O$ ETHYL ETHER C_2H_5-O-C_2H_5
$+2H_2O$ -2HCl
$+H_2O$ -HCl ETHYLENE GLYCOL HO-C-C-OH
$+H_2O$
OXIDATION SEE CHART VII
+O ETHYL ALCOHOL HC-C-OH
$+H_2$ $-H_2$
+O -2H ACETALDEHYDE
-O +O
+2 O -2H ACETIC ACID
+2 O CARBON MONOXIDE 2CO HYDROGEN $3H_2$
+7 O CARBON DIOXIDE $2CO_2$ WATER $3H_2O$
+HCl $-H_2O$ ETHYL CHLORIDE HC-C-Cl
$+CH_3COOH$ $-H_2O$ ETHYL ACETATE $C_2H_5CO_2CH_3$
$+CH_3COOH$ $-H_2O$ ACETIC ANHYDRIDE
$+CH_3COOH$ $-H_2O$ $-CO_2$ ACETONE
HALOGENATION SEE CHART VIII
+Cl ETHYL CHLORIDE HC-C-Cl
+2Cl -2H ETHYLENE CHLORIDE Cl-C-C-Cl
+6Cl -6H HEXACLORO-ETHANE Cl-C-C-Cl
+Pb $+3C_2H_5Cl$ -4Cl TETRAETHYL LEAD
-HCl VINYL CHLORIDE CH_2=CHCl
NITRATION SEE CHART IX
NITROETHANE HC-C-NO_2
+H -O ETHYL AMINE HC-C-N-H_2
+HCHO 2-NITRO-1-PROPANOL
$+H_2SO_4$ HYDROXYLAMINE SULFATE NH_2OH-H_2SO_4 ACETIC ACID
$+H_2$ $-O_2$ 2-AMINO 1-PROPANOL

H_2O	WATER
C_2H_2	ACETYLENE
HCl	HYDROGEN CHLORIDE
$ISO\text{-}C_4H_{10}$	ISOBUTANE
C_2H_4	ETHYLENE
C_2H_5OH	ETHYL ALCOHOL
$CH_3C^{O}OH$	ACETIC ACID
C_2H_5Cl	ETHYL CHLORIDE
Pb	LEAD
HCHO	FORMALDEHYDE
H_2SO_4	SULFURIC ACID

CHART IV

FOUR CHIEF REACTIONS AS APPLIED TO ETHANE

THESE REACTIONS ARE PURPOSELY SIMPLIFIED FOR COMPARISON. REACTIONS OF THE CONVENTIONAL TYPE MAY BE FOUND IN TEXT BOOKS OF ORGANIC CHEMISTRY.

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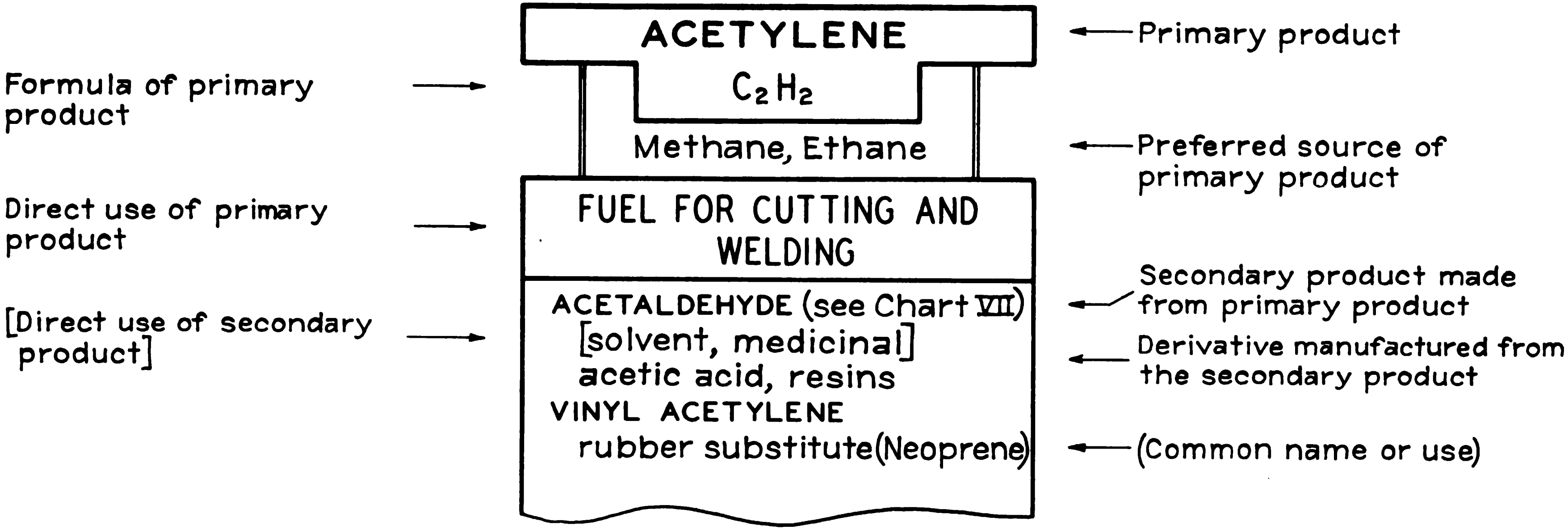
CHART V


ACETYLENE
C_2H_2
Methane, Ethane
FUEL FOR CUTTING AND WELDING
ACETALDEHYDE (see Chart VII)
[solvent, medicinal]
acetic acid, resins
VINYL ACETYLENE
rubber substitute(Neoprene)
Formula of primary product
Direct use of primary product
[Direct use of secondary product]
Primary product
Preferred source of primary product
Secondary product made from primary product
Derivative manufactured from the secondary product
(Common name or use)

Original from THE OHIO STATE UNIVERSITY

Nitration of methane is possible if operating conditions are drastic enough. Thus, methane, the most prevalent of all hydrocarbon gases, is more resistant to chemical treatment than the others, and its reactions are less typical as is often true for first members of an homologous series of compounds. The utilization of methane other than as a gaseous fuel is still a problem awaiting solution.

This brief discussion regarding methane also brings out the fact that for each hydrocarbon there is one set of operating conditions - temperature, pressure, and contact time - that will provide optimum yields. For this reason it is often desirable to segregate the hydrocarbons as individuals or small groups. For example, if it is desired to decompose propane thermally to produce propylene, then any butane, pentane, or other higher-molecular-weight hydrocarbons should be removed. These heavier compounds react to produce undesirable products under conditions suitable for propane. On the other hand, methane and ethane would react very little, and would serve largely as diluents to decrease the extent of the propane decomposition.

Chart IV.

Chart IV gives in some detail the relationship between various reactions that may be applied to ethane. No attempt is made to show the mechanism of the reactions indicated - simply the over-all results. The (+) sign before a product name means that the product is added, and the (-) sign means that the product is removed. Text books on organic chemistry describe the conditions under which such reactions will occur. The chart is by no means complete and is presented only to illustrate the types of reaction possible in the synthesis of products from gaseous hydrocarbons.

Chart V.

Chart V should be used for reference in studying charts VI to X, as it indicates the significance of the several "boxes," brackets, and types of lettering used in them. In chart V the terms used have the following meanings:

Primary product.- A product obtained directly by the application of one of the four basic methods of conversion given in chart III.

Preferred source.- Not necessarily the only source, but the material reacting most easily or with the best yields.

Direct use.- A use, (1) in which no chemical change occurs in the substance, as when it is used as a solvent or anesthetic; or, (2) when the substance is completely destroyed, as when used for fuel. The direct uses of secondary products are indicated in brackets.

Secondary product.- A product made from the primary product. Common names and uses of secondary products and their derivatives are indicated in parentheses.

Charts VI - IX.

Charts VI, VII, VIII, and IX show the development of chemical synthe from the primary products obtained by the application of the four methods of hydrocarbon conversion shown in chart III. Space does not permit nami all secondary products. For example, one company lists about 85 organic chemicals, of which they say: "In producing all these chemicals, olefins derived by processing natural gas are used either directly or indirectly as raw materials and in most cases as the most important raw material." Williams[5] shows a chart of 71 products that can be made, beginning with just one olefin, isobutylene. A company manufacturing nitration products lists 54 derivatives as an incomplete list of those that can be made available easily. These data show the impracticability of listing all th products, and indicate the magnitude of the industry being built with natural gas as a raw material. It should be mentioned that a well-established group of organic compounds also is being prepared from the pentanes, which are not constituents of "dry" or "liquefied" natural gas. They are present, however, in natural gasoline.

Chart X.

Certain constituents of natural gas are not hydrocarbons and usually are present in relatively small amounts. Some of these materials, such as helium, are valuable even when present only to the extent of a few percent. Others, such as hydrogen sulfide, are a source of trouble and must be removed even when they are present in small quantities. Hydrogen sulfide is an example of one of the generally objectionable nonhydrocarbo gases, which may become valuable when it is removed from the other components of natural gas and converted into useful products.

Some natural gases have a composition of nearly 100 percent carbon dioxide. Carbon dioxide from this source may be of value if the wells from which it is produced are geographically situated so that the gas may be utilized economically. So far, no economic use for nitrogen in natural gas has been developed.

ACKNOWLEDGMENTS

Collection and arrangement of the information presented in this paper were carried out under the general supervision of R. A. Cattell, chief engineer, Petroleum and Natural Gas Division, Bureau of Mines, Washington, D. C., and N. A. C. Smith, supervising engineer, Petroleum Experiment Station, Bartlesville, Okla.

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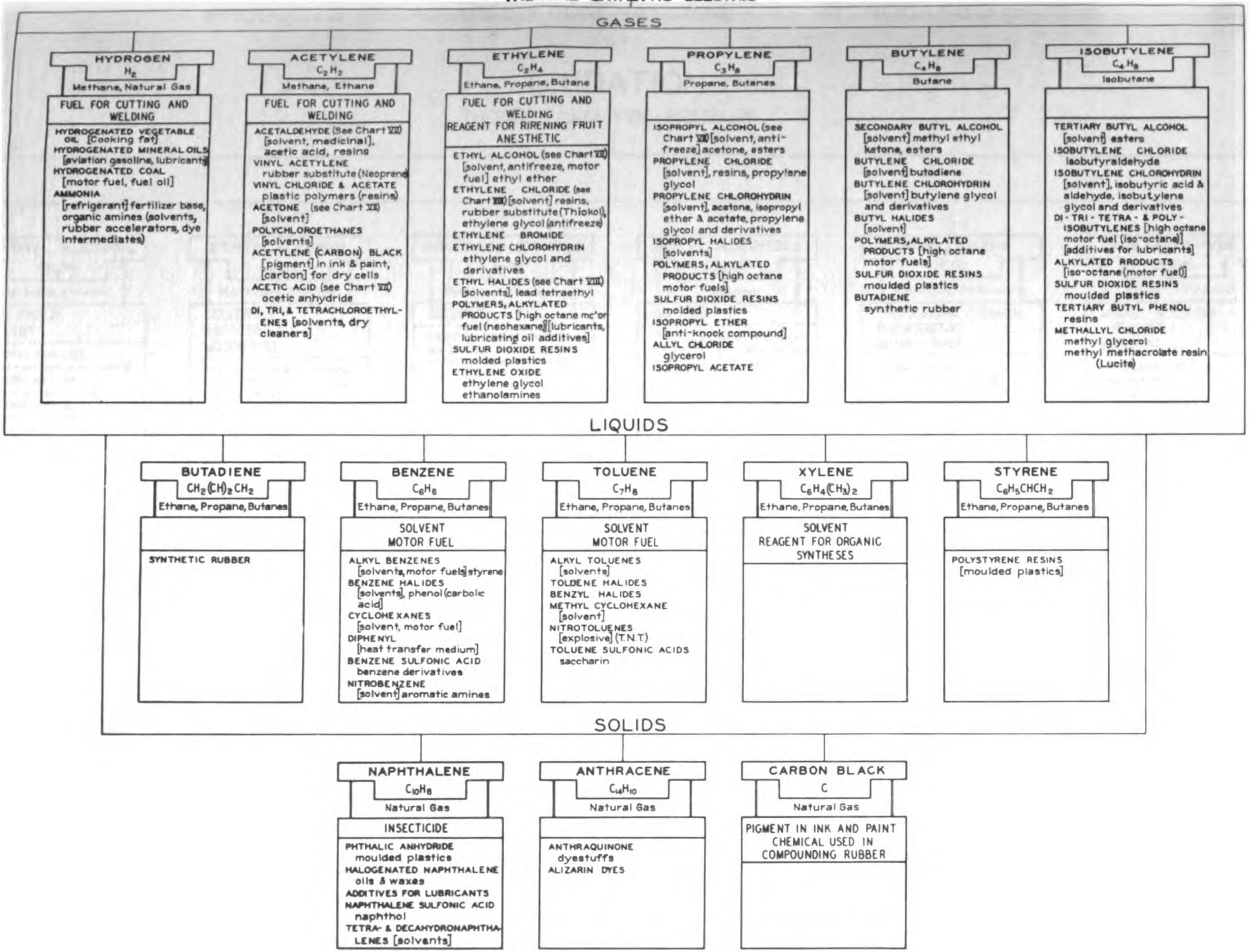
[5] Williams, E. C., Creating Industries, 1919-1939 - Petroleum: Chem. Ind., vol. 44, May 1939, p. 495.

THERMAL—CATALYTIC—ELECTRIC



GASES

HYDROGEN
H_2
Methane, Natural Gas

FUEL FOR CUTTING AND WELDING

HYDROGENATED VEGETABLE OIL [Cooking fat]
HYDROGENATED MINERAL OILS [aviation gasoline, lubricants]
HYDROGENATED COAL [motor fuel, fuel oil]
AMMONIA [refrigerant] fertilizer base, organic amines (solvents, rubber accelerators, dye intermediates)

ACETYLENE
C_2H_2
Methane, Ethane

FUEL FOR CUTTING AND WELDING

ACETALDEHYDE (See Chart VII) [solvent, medicinal], acetic acid, resins
VINYL ACETYLENE rubber substitute (Neoprene)
VINYL CHLORIDE & ACETATE plastic polymers (resins)
ACETONE (see Chart VII) [solvent]
POLYCHLOROETHANES [solvents]
ACETYLENE (CARBON) BLACK [pigment] in ink & paint, [carbon] for dry cells
ACETIC ACID (see Chart VII) acetic anhydride
DI, TRI, & TETRACHLOROETHYLENES [solvents, dry cleaners]

ETHYLENE
C_2H_4
Ethane, Propane, Butane

FUEL FOR CUTTING AND WELDING
REAGENT FOR RIRENING FRUIT
ANESTHETIC

ETHYL ALCOHOL (see Chart VII) [solvent, antifreeze, motor fuel] ethyl ether
ETHYLENE CHLORIDE (see Chart VIII) [solvent] resins, rubber substitute (Thiokol), ethylene glycol (antifreeze)
ETHYLENE BROMIDE
ETHYLENE CHLOROHYDRIN ethylene glycol and derivatives
ETHYL HALIDES (see Chart VIII) [solvents], lead tetraethyl
POLYMERS, ALKYLATED PRODUCTS [high octane motor fuel (neohexane)] [lubricants, lubricating oil additives]
SULFUR DIOXIDE RESINS molded plastics
ETHYLENE OXIDE ethylene glycol ethanolamines

PROPYLENE
C_3H_6
Propane, Butanes

ISOPROPYL ALCOHOL (see Chart VII) [solvent, anti-freeze] acetone, esters
PROPYLENE CHLORIDE [solvent], resins, propylene glycol
PROPYLENE CHLOROHYDRIN [solvent], acetone, isopropyl ether & acetate, propylene glycol and derivatives
ISOPROPYL HALIDES [solvents]
POLYMERS, ALKYLATED PRODUCTS [high octane motor fuels]
SULFUR DIOXIDE RESINS molded plastics
ISOPROPYL ETHER [anti-knock compound]
ALLYL CHLORIDE glycerol
ISOPROPYL ACETATE

BUTYLENE
C_4H_8
Butane

SECONDARY BUTYL ALCOHOL [solvent] methyl ethyl ketone, esters
BUTYLENE CHLORIDE [solvent] butadiene
BUTYLENE CHLOROHYDRIN [solvent] butylene glycol and derivatives
BUTYL HALIDES [solvent]
POLYMERS, ALKYLATED PRODUCTS [high octane motor fuels]
SULFUR DIOXIDE RESINS moulded plastics
BUTADIENE synthetic rubber

ISOBUTYLENE
C_4H_8
Isobutane

TERTIARY BUTYL ALCOHOL [solvent] esters
ISOBUTYLENE CHLORIDE isobutyraldehyde
ISOBUTYLENE CHLOROHYDRIN [solvent], isobutyric acid & aldehyde, isobutylene glycol and derivatives
DI - TRI - TETRA - & POLY - ISOBUTYLENES [high octane motor fuel (iso-octane)] [additives for lubricants]
ALKYLATED RRODUCTS [iso-octane (motor fuel)]
SULFUR DIOXIDE RESINS moulded plastics
TERTIARY BUTYL PHENOL resins
METHALLYL CHLORIDE methyl glycerol methyl methacrolate resin (Lucite)

LIQUIDS

BUTADIENE
$CH_2(CH)_2CH_2$
Ethane, Propane, Butanes

SYNTHETIC RUBBER

BENZENE
C_6H_6
Ethane, Propane, Butanes

SOLVENT
MOTOR FUEL

ALKYL BENZENES [solvents, motor fuels] styrene
BENZENE HALIDES [solvents], phenol (carbolic acid)
CYCLOHEXANES [solvent, motor fuel]
DIPHENYL [heat transfer medium]
BENZENE SULFONIC ACID benzene derivatives
NITROBENZENE [solvent] aromatic amines

TOLUENE
C_7H_8
Ethane, Propane, Butanes

SOLVENT
MOTOR FUEL

ALKYL TOLUENES [solvents]
TOLUENE HALIDES
BENZYL HALIDES
METHYL CYCLOHEXANE [solvent]
NITROTOLUENES [explosive] (T.N.T.)
TOLUENE SULFONIC ACIDS saccharin

XYLENE
$C_6H_4(CH_3)_2$
Ethane, Propane, Butanes

SOLVENT
REAGENT FOR ORGANIC SYNTHESES

STYRENE
$C_6H_5CHCH_2$
Ethane, Propane, Butanes

POLYSTYRENE RESINS [moulded plastics]

SOLIDS

NAPHTHALENE
$C_{10}H_8$
Natural Gas

INSECTICIDE

PHTHALIC ANHYDRIDE moulded plastics
HALOGENATED NAPHTHALENE oils & waxes
ADDITIVES FOR LUBRICANTS
NAPHTHALENE SULFONIC ACID naphthol
TETRA- & DECAHYDRONAPHTHALENES [solvents]

ANTHRACENE
$C_{14}H_{10}$
Natural Gas

ANTHRAQUINONE dyestuffs
ALIZARIN DYES

CARBON BLACK
C
Natural Gas

PIGMENT IN INK AND PAINT
CHEMICAL USED IN COMPOUNDING RUBBER

Original from THE OHIO STATE UNIVERSITY

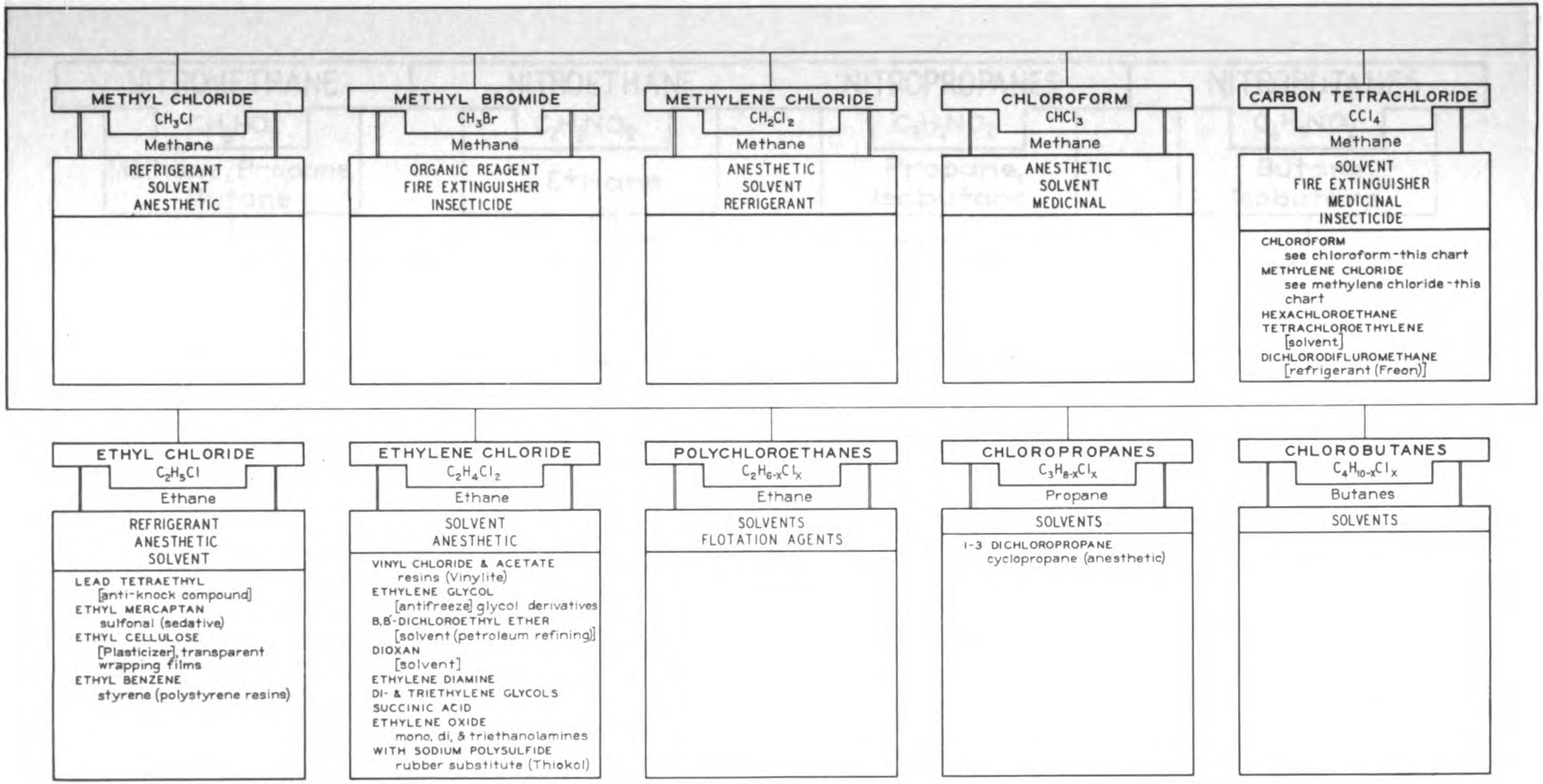
PRODUCTS OBTAINABLE FROM NATURAL GAS HYDROCARBONS
BY
OXIDATION
THERMAL-CATALYTIC-PRESSURE

METHYL ALCOHOL	CH_3OH	Methane, Ethane	ANTI-FREEZE SOLVENT	METHYL HALIDES [refrigerants, solvents] METHYL ESTERS [lacquer solvents] FORMALDEHYDE see Formaldehyde-this chart METHYL ETHER [refrigerant, solvent]
ETHYL ALCOHOL	C_2H_5OH	Methane, Ethane	SOLVENT ANTI-FREEZE MOTOR FUEL	ACETIC ACID-see Acetic Acid-this chart ACETALDEHYDE see Acetaldehyde-this chart DIETHYL ETHER [anesthetic, solvent] ETHYL CHLORIDE [refrigerant, anesthetic] [solvent] lead tetraethyl ETHYL IODIDE and BROMIDE ETHYL ESTERS METALLIC ETHYLATES
PROPYL ALCOHOLS	C_3H_7OH	Propane, Butane	SOLVENT	PROPYL COMPOUNDS such as propyl halides, esters, ethers, aldehydes, acids, ketones
BUTYL ALCOHOLS	C_4H_9OH	Butane	SOLVENT	BUTYL COMPOUNDS such as butyl halides, esters, ethers, aldehydes, acids, ketones
FORMALDEHYDE	HCHO	Methane, Ethane	PHOTOGRAPHIC CHEMICAL PRESERVATIVE DISINFECTANT	FORMIC ACID PARAFORMALDEHYDE disinfectant PHENOLIC RESINS [Bakelite, Synthane, Redmanol] HEXAMETHYLENE-TETRAMINE urotropin (medicinal) METHYL AMINES CASEIN RESINS moulded plastics UREA RESINS
ACETALDEHYDE	CH_3CHO	Ethane, Propane	MIRROR SILVERING REAGENT MEDICINAL	PARALDEHYDE [soporific] ETHYL ALCOHOL see Ethyl Alcohol-this chart ACETIC ACID see Acetic Acid-this chart RESINS DYESTUFFS n-BUTYL, HEXL and OCTYL ALCOHOLS
ACETONE	CH_3COCH_3	Propane	SOLVENT FOR explosives, oils, waxes, resins, lacquers, rubber, celluloid, acetylene, etc.	MEDICINALS sulfonal (soporific) DIACETONE ALCOHOL hexyl alcohols KETENES acetic anhydride, diketenes
FORMIC ACID	HCOOH	Methane, Ethane Propane	CHEMICAL USED in the electroplating, dying and tanning industries	
ACETIC ACID	CH_3COOH	Butane	SOLVENT MEDICINAL	METALLIC SALTS [insecticides] dyestuffs ACETONE see Acetone-this chart ACETIC ANHYDRIDE acetylating reagent CELLULOSE ACETATE non-inflammable films ALKYL ACETATES ACETALDEHYDE see acetaldehyde-this chart
ACETYLENE	C_2H_2	Methane	SEE ACETYLENE CHART VI	
CARBON DIOXIDE	CO_2	Natural Gas	FIRE EXTINGUISHER REFRIGERANT (DRY ICE)	
HYDROGEN **CARBON MONOXIDE**	H_2 CO	Methane		METHYL ALCOHOL see Methyl Alcohol-this chart n-PROPYL ALCOHOL see Propyl Alcohol-this chart ISOBUTYL ALCOHOL see Butyl Alcohols-this chart SYNTHETIC HYDROCARBONS-KOGASIN AND PARAFFIN WAX [motor fuel, lubricants] fatty acids, alcohols

Original from THE OHIO STATE UNIVERSITY

CHART VIII

PRODUCTS OBTAINABLE FROM NATURAL GAS HYDROCARBONS
BY
HALOGENATION
THERMAL - CATALYTIC - PHOTOSYNTHETIC

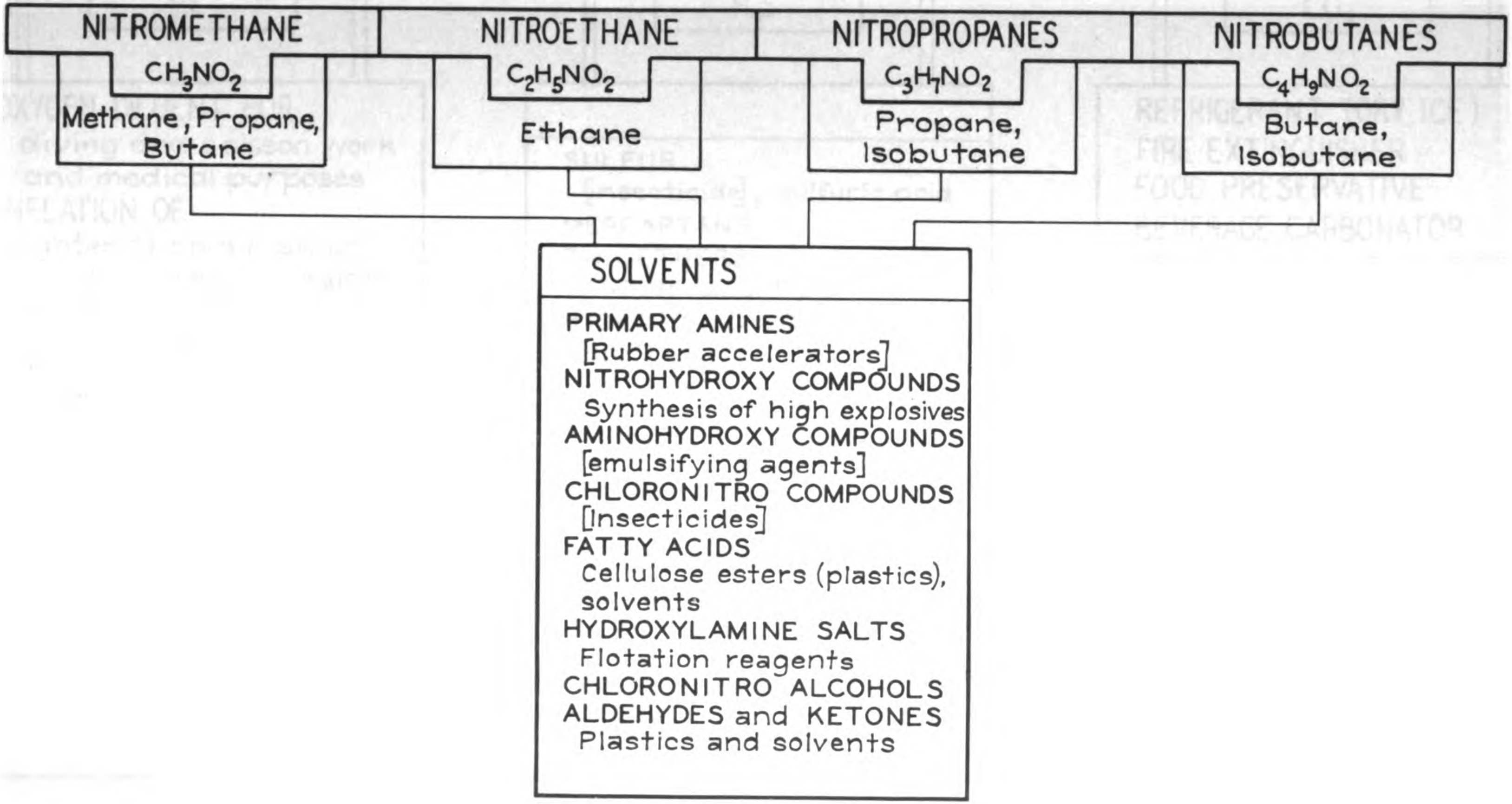


PRODUCTS OBTAINABLE FROM NATURAL GAS HYDROCARBONS

BY

NITRATION

THERMAL



NITROMETHANE
CH_3NO_2
Methane, Propane, Butane

NITROETHANE
$C_2H_5NO_2$
Ethane

NITROPROPANES
$C_3H_7NO_2$
Propane, Isobutane

NITROBUTANES
$C_4H_9NO_2$
Butane, Isobutane

SOLVENTS

PRIMARY AMINES
[Rubber accelerators]
NITROHYDROXY COMPOUNDS
Synthesis of high explosives
AMINOHYDROXY COMPOUNDS
[emulsifying agents]
CHLORONITRO COMPOUNDS
[Insecticides]
FATTY ACIDS
Cellulose esters (plastics), solvents
HYDROXYLAMINE SALTS
Flotation reagents
CHLORONITRO ALCOHOLS
ALDEHYDES and KETONES
Plastics and solvents

USES OF NON-HYDROCARBON NATURAL GAS CONSTITUENTS

HELIUM
HE

OXYGEN DILUENT FOR
diving and caisson work
and medical purposes
INFLATION OF
lighter than air ships,
toy and meteorological
balloons
ELECTRIC DISCHARGE TYPE
SIGNS
PRESERVATIVE

HYDROGEN SULFIDE
H_2S

SULFUR
[insecticide], sulfuric acid
MERCAPTANS
THIOETHERS
CARBON DISULFIDE
HYDROGEN CHLORIDE
THIOSULFATES

CARBON DIOXIDE
CO_2

REFRIGERANT (DRY ICE)
FIRE EXTINGUISHER
FOOD PRESERVATIVE
BEVERAGE CARBONATOR

Much of the information contained in this circular was obtained
irectly from companies in the petroleum and chemical industries in
eply to requests for data relating to hydrocarbon utilization. The re-
onse to these requests was gratifying, and the writer is pleased to
knowledge his indebtedness to all who contributed.

The writer is also particularly appreciative of the criticisms of
he paper by members of the Petroleum Division both at Bartlesville and
he other stations and field offices, by members of petroleum company
aboratories, by Dr. H. B. Hass, head of the Department of Chemistry at
rdue University, Lafayette, Ind., and J. C. Walker, general superin-
endent, Chemical Division, Cities Service Oil Co., Bartlesville, Okla.
he charts were drawn by Ralph Wright and Russell Himmelright of the
artlesville Station.

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